CORRIM: Phase II Final Report

Module I

Life-Cycle Assessments of Subassemblies Evaluated at the Component Level

December 2009

Prepared by:

Bruce Lippke[1]

Lucy Edmonds

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[1] Lippke is President Emeritus CORRIM (The Consortium for Research on Renewable Industrial Materials) and Professor Emeritus School of Forestry, University of Washington. Lucy Edmonds is a Research Consultant and previous Graduate Research Assistant at the University of Washington.

Executive Summary

While it is evident from the life cycle analysis of house designs that wood framing generally produces lower environmental burdens than concrete or steel alternatives just how to go about selecting best products or process changes (such as biofuel drying) is difficult. By analyzing the impacts at the level of components and those components most critical in structural assemblies, strategies for environmental improvement become more obvious.

As noted in figure 1, the wood floor-joist ***components*** that are used in the construction of floors (dimension wood joist {Dim-Joist} and Engineered Wood I-Joists {EWP I-Joist} both store carbon (negative emissions) as their emissions from processing are more than offset by the carbon removed from a sustainably managed carbon neutral forest that becomes carbon stored in the products. In contrast, the non-wood Concrete Slab and Steel Joists result in substantial carbon emissions (2-4 $kgCO_2$/sq ft of floor). Adding a wood covering (plywood {Ply} or oriented strandboard {OSB}) to steel joists for a ***floor-assembly*** does not offset the emissions from the heavy gauge steel that is used in flooring. EWP I-joists with wood covering store less carbon than dimension joists because they use less fiber but all combinations of wood joist and wood covering store substantial amounts of carbon compared to non-wood joists and floor covering which result in significant emissions.

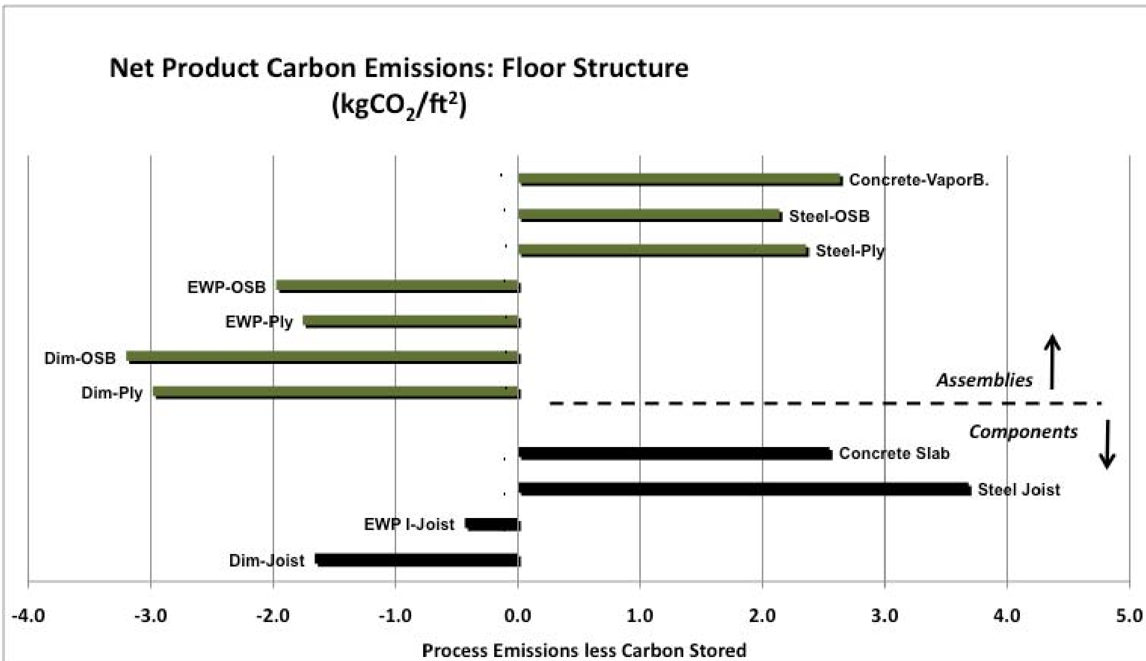

Figure ES-1. Process Emissions less Carbon Stored in Floor Structure Components and Assemblies (source: Appendix Module I)

The EWP I-joist with an OSB cover is substantially better than a concrete slab reducing GWP emissions by 3 kg per sq. ft. of floor. Another measure of interest is the emission reduction relative to the fiber used as an efficiency of substitution measure. The EWP I-joist reduces CO_2 emissions by 4.6 kg per kg (dry weight) of wood used. The comparison with steel joists and OSB cover reduces emissions by 9.8 kg per sq. ft., more than twice as effective as the substitution for a concrete floor largely because steel joists must be heavy gauge to minimize floor bounce resulting in substantial processing emissions, a relatively poor application for steel. But since the steel floor also uses wood in the floor cover as a partial carbon offset it is less fiber efficient reducing emissions to 4.2 kg per kg of wood used, slightly less than by displacing concrete flooring. If there is an adequate supply of wood, greater use of wood will improve the carbon footprint in structures the most. If not, efficient use of fiber becomes important.

While displacing steel in floors by wood is more effective than displacing concrete these findings cannot be generalized to wall assemblies. As noted in figure 2, the wood-wall ***components*** (kiln dried stud {KDStud}, green stud or biofuel dried stud{BioDryStud}), Plywood{Ply}), OSB, biofuel dried plywood {BioDryPly}) all store carbon more than offsetting their processing emissions, and some ***wall assemblies*** use sufficient amounts of wood to more than offset the emissions of some non-wood components such as the emissions from the use of vinyl cladding. As a component, concrete block substitutes not only for wood studs, but also the wood sheathing and with the addition of a stucco cladding for any wood or vinyl cladding used with wood framed walls. The best configurations use wood products with biofuel used for drying. The assembly made of biofuel dried studs, biofuel dried plywood in both sheathing and cladding stores the most net carbon with the use of OSB sheathing almost as good.

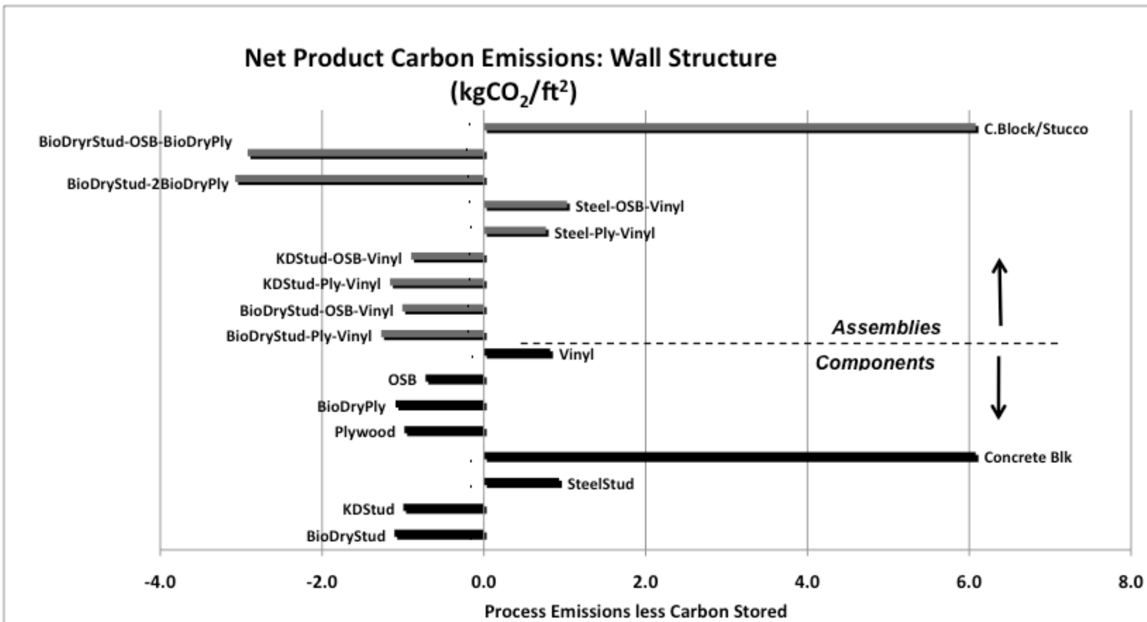

Figure ES-2. Process Emissions less Carbon Stored for Wall Components and Assemblies

The green stud (or biofuel dried) with biofuel dried plywood sheathing and biofuel dried plywood cladding substitution for the more conventional kiln dried stud with OSB sheathing and vinyl siding reduces GWP by over 2.2 kgCO_2 per sq. ft. of wall with a fiber efficiency of 2.1 kg CO_2 reduction per 1kg of fiber used (top bars). The benefit of this within wood substitution is almost the same as replacing a conventional steel wall assembly with a conventional wood assembly, which involves no increased use of biofuel in drying. By doing both, increasing the use of biofuel and substituting for a steel framed wall assembly, GWP emissions are reduced by 4.1 kgCO_2 per sq. ft. of wall with a fiber substitution efficiency of 2.7 kgCO_2 per kg of wood fiber used.

Using the wood designs compared to a concrete and stucco wall result in GWP reductions of 7-9 kgCO_2 per sq. ft. of wall or almost 3.5 kgCO_2 per 1 kg use of fiber. While the wood is more effective at displacing the emissions from steel in floors and concrete in walls the displacement of emissions per unit of wood fiber used is not as different. The use of more fiber is a substantial part of the opportunity for improvements but may not provide the high leverage that is provided by critical component comparisons such as steel joists vs EWP I-joist. Using more fiber as biofuel in products helps to reduce the GWP in structural assemblies by reducing fossil fuel emissions in processing but will not likely be as efficient as using fiber for structural components. It still may be the best use of low quality fiber not suitable for engineering into structural components. However, different components do perform better in different applications and these differences are not generally identified or valued in current market exchanges.

This sampling of materials and designs is not exhaustive but suggests many design, product and process changes that can improve environmental performance. The most obvious include (1) using a renewable wood resource instead of a fossil intensive resource and especially where the substitution advantage is large, (2) using biofuels to reduce the fossil fuel use in manufacturing wood, (3) using resource efficient materials pre-cut to length or pre-assembled units and (4) using recycled materials that require less energy. The results also suggest the potential for many future improvements in the design of components that can displace the higher energy components and the design of new pre-assembled units that can gain several of these advantages at once.

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1. Introduction

The CORRIM Phase I Research Plan evaluated the environmental impacts of wood frame structures for a cold climate (Minneapolis) compared to steel frame and for a warm climate (Atlanta) compared to concrete block walls (Perez-Garcia et al 2005). While the results generally show lower environmental burdens for wood framing, the aggregation of so many materials made it difficult to identify best pathways to environmental improvement, the primary objective of Life Cycle Assessment (Lippke and Bowyer 2007). To better guide environmental improvement analysis, understanding the impacts at a components level or building sub-assembly level became an important objective of the Phase II Research Plan. We analyzed examples of a range of wall and floor assemblies, which suggested we might learn even more by understanding the impacts at the level of substitutable components. Early results analyzing burdens for the components in Minneapolis and Atlanta walls and floors were reported on in Lippke and Edmonds (2006). In this module, we provide energy use and Life Cycle Assessment measures for a range of loadbearing wall assemblies, then look at environmental impacts for a range of individual components frequently used in such assemblies. Finally we compare a range of wall and floor assemblies focusing on carbon accounting that includes the impact of the carbon stored in products. Comparing assemblies provides a basis for understanding the environmental principles of product substitution as each component has different strengths and weakness in both structural and environmental performance.

2. Energy Requirements and Environmental Burdens for Fire Rated Assemblies

Energy requirements and environmental burdens associated with AFPA *wood-frame***,** fire-rated wall assemblies are assessed for alternative wood and steel based designs. The comparisons demonstrate that product selection and design provide substantial opportunities to reduce environmental burdens.

Table 1, taken from the AFPA website, lists the components of four different fire-rated wood-frame wall assemblies used in this analysis.

Table 1. AFPA One-Hour Fire-Rated Load bearing Wood-Frame Wall Assemblies. Assemblies Rated from One Side (Fire on Interior Only)

Studs	Insulation		Sheathing	Fasteners	
2x4 @ 16" o.c.	3½" mineral wool batts	**I**	5/8" Type X Gypsum Wallboard (**H**)	2¼" #6 Type S drywall screws @ 12" o.c.	WS4-1.2
		E	3/8" wood structural panels (**V**)	6d common nails @ 6" edges/12" field	
2x4 @ 16" o.c.	4 mil polyethylene 3½" mineral wool batts	**I**	5/8" Type X Gypsum Wallboard (**V**)	6d cement coated box nails @ 7" o.c.	WS4-1.3
		E	½" fiberboard (**V**)	1½" roofing nails @ 3" edges/6" field	
			3/8" hardboard shiplapped panel siding	8d galv. nails @ 4" edges/8" field	
2x6 @ 16" o.c.	5½" mineral wool batts	**I**	5/8" Type X Gypsum Wallboard (**H**)	2¼" #6 Type S drywall screws @ 12" o.c.	WS6-1.3
		E	7/16" wood structural panels (**V**)	6d common nails @ 6" edges/12" field	
2x6 @ 16" o.c.	R-19 fiberglass insulation	**I**	5/8" Type X Gypsum Wallboard (**V**)	2¼" #6 Type S drywall screws @ 12" o.c.	WS6-1.5
		E	3/8" wood structural panels (**V**)	6d common nails @ 6" edges/12" field	

H - applied horizontally with vertical joints over studs **I** - Interior sheathing
V - applied vertically with vertical joints over studs **E** - Exterior sheathing

Table 2 provides the components associated with four alternative load-bearing exterior wall designs. "Lumber wall" is framed with 2X6 wood studs at 16 o.c. and includes R19 fiberglass batt insulation, a 6 mil polyethylene barrier, ½" gypsum on the inside, ½" OSB sheathing, and vinyl siding on the outside. The "Steel wall" is similar to the Lumber wall but uses 2X4 steel studs, R13 fiberglass, and 1.5" extruded polystyrene insulation. The wall titled "Lumber w/subs (OSB)" substitutes traditional wall coverings with OSB and uses recycled paper for insulation. The lumber and OSB used in the "Lumber w/subs (OSB)" wall is produced with above-average levels of biofuels and therefore reduced levels of fossil fuels. The "Lumber w/subs (ply)" design is similar to the Lumber w/subs (OSB) design with plywood substituting for OSB.

Table 2. Alternative Loadbearing Wall Assemblies.

Studs	Insulation	Sheathing		
2x6 wood studs @ 16" o.c.	6 mil polyethylene	**I**	1/2" regular gypsum	Lumber Wall
	R-19 fiberglass insulation	**E**	1/2" OSB	
			Vinyl cladding	
2x4 steel studs @ 16" o.c.	6 mil polyethylene	**I**	1/2" regular gypsum	Steel Wall
	R-13 fiberglass insulation	**E**	1/2" OSB	
	1.5" extruded polystyrene		Vinyl cladding	
2x6 wood studs* @ 16" o.c.	6 mil polyethylene	**I**	1/4" OSB* (replaces gypsum)	Lumber w/subs (OSB)
	Recycled paper insulation	**E**	1/2" OSB*	
			1/2" OSB* (replaces vinyl)	
2x6 wood studs* @ 16" o.c.	6 mil polyethylene	**I**	1/4" Plywood* (replaces gypsum)	Lumber w/subs (ply)
	Recycled paper insulation	**E**	1/2" Plywood *	
			1/2" Plywood * (replaces vinyl)	

***** Produced with higher than average levels of biofuel
I - Interior sheathing **E** - Exterior sheathing

Using Athena Environmental Impact Estimator™ (EIE), the burdens associated with each of the eight wall designs were compared (ATHENA Institute EIE 2004). The EIE model develops the structural assemblies for buildings, and their bill of materials, accesses LCI profiles for each component in a bill of materials in order to accumulate the impacts at the assembly or full structure level and makes comparisons across alternatives. The LCI profiles are sourced from research by experts in each industry with the objective of using the NREL USLCI database of wood and non-wood products as a science based and reviewed source of product LCIs for LCA practioners.

Minneapolis, Minnesota was inputted into Athena EIE as the construction site for each of the walls; therefore results presented here may be regionally specific. All results are provided in a per square foot of wall area basis. Figure 1 provides a comparison of the Total Energy (MJ/ft.^{2}) and the Fossil Fuel energy (MJ/ft.^{2}) consumed by the eight wall designs. The Steel wall consumes the largest amount of total and fossil fuel energy per unit area. The Lumber wall's thicker studs and additional insulation may explain its greater total and fossil fuel energy consumption than the WS4-1.2 and WS4-1.3 walls and its vinyl cladding and 6 mil polyethylene vapor barrier may explain its greater energy consumption than

AFPA's WS6-1.3 and WS6-1.5. The wood product and biofuel substitutions used (an increase in biofuel use over current levels) in the two Lumber w/subs wall designs significantly reduces the total and fossil fuel energies required when compared with the more traditionally designed Lumber wall.

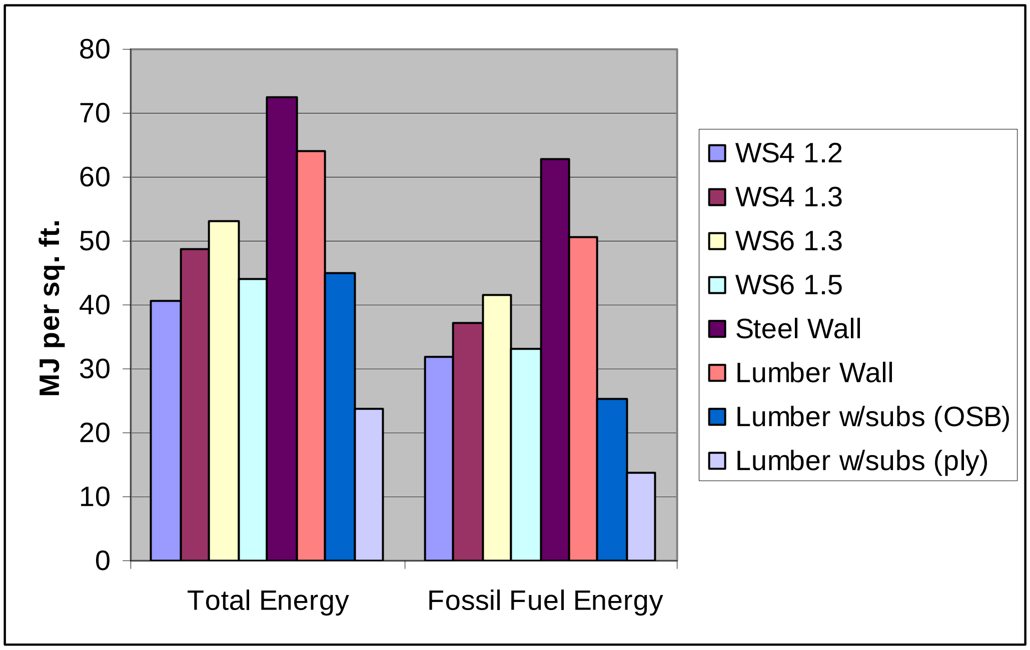

Figure 1. Energy consumption per exterior wall assembly design

The factor of 4 range in fossil fuel energy, the primary driver of carbon emission impacts, suggests the importance of understanding the role of each component.

3. Energy Requirements for Wall Assembly Components

Table 3 provides energy consumption data for each of the wall design components; illuminating the differences in energy consumption shown in Figure 1. For example, if 2X6 wood studs are used instead of 2X4 steel studs, the fossil fuels consumed by framing members will be reduced by 37%. Selecting 3/8” cedar shiplap for external cladding instead of vinyl reduces the total energy consumed by cladding by 82% and fossil fuels by 88%. Selecting ¼” plywood produced with above average levels of biofuels as an interior wall covering instead of ½” gypsum reduces total energy consumed by the interior wall covering by 62% and fossil fuels by 84%. The reduction in total energy (6%) and fossil fuels (26%) realized by selecting ½” OSB sheathing produced with above-average levels of biofuels instead of more representative levels demonstrates the significance of substituting biofuels for fossil fuels.

Table 3. Energy requirements for Wall Assembly Components (per square foot).

Assembly Components	Total Energy (MJ)	Fossil Fuel Energy (MJ)
2X4 Lumber Studs	7.38	4.35
2X6 Lumber Studs	11.05	6.39
2X6 Lumber Studs*	3.45	2.90
2X4 Steel Studs	10.88	10.07
3.5" Rockwool	12.36	11.76
5.5" Rockwool	19.29	18.35
R13 Fiberglass	7.68	7.09
R19 Fiberglass	11.94	11.02
1.5" EPS	12.77	12.29
Recycled Paper Insulation	3.98	3.67
1 layer 5/8" gypsum X	9.55	8.85
1 layer 1/2" gypsum reg	7.67	7.08
3/8" OSB	11.45	6.91
7/16" OSB	13.36	8.07
1/2" OSB	15.27	9.22
1/4" OSB*	7.15	3.43
1/2" OSB*	14.29	6.85
1/2 Plywood	5.86	3.06
1/4" Plywood*	2.90	1.10
1/2 Plywood*	5.79	2.21
3/8" Shiplap	3.02	1.84
Vinyl	16.55	15.34
4 mil Poly Vapor	1.15	1.09
6 mil Poly Vapor	1.72	1.63

* Indicates product produced with above-average levels of biofuels.

4. Life Cycle Assessment Indices for Wall Designs

Figure 2 shows the Life Cycle Assessment indices for three environmental burdens associated with the wall designs: Solid Waste, Air Pollution Index (API), and Global Warming Potential (GWP) where GWP is measured as carbon equivalent impacts of three greenhouse gases (CO_2, NO_x and methane). The Steel wall design produces less solid waste than most of the wood-based designs because, unlike wood studs, steel members are frequently cut to length before being shipped to the construction site. The Lumber w/subs (with OSB) design is impacted by comparatively higher levels of sulphur oxide (a main API contributor) during OSB's manufacture. WS6-1.3 and the Lumber wall have almost identical GWPs, indicating that the GWP associated with WS6-1.3's 5.5" rockwool insulation is essentially equivalent to the Lumber wall's R19 fiberglass, vinyl cladding and 6 mil polyethylene vapor barrier. With the exception of OSB's influence on API, substituting wood products and biofuels where possible tends to reduce the three environmental burdens shown here, as indicated by the two Lumber w/subs designs.

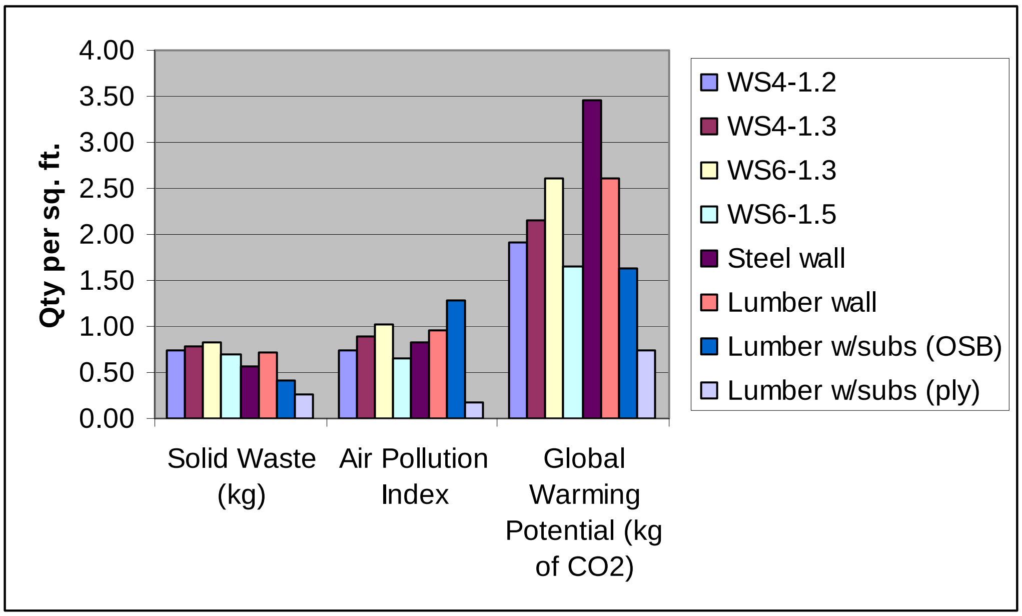

Figure 2. Environmental burdens per exterior wall assembly design

Table 4 provides environmental burdens associated with the components for each of the wall designs; illuminating the differences in environmental burdens shown in Figure 2. For example, if ½" plywood sheathing is selected in place of ½" OSB, the Air Pollution Index associated with sheathing will be reduced by almost 94%. If 3/8" cedar shiplap is selected instead of vinyl for the exterior cladding, the Global Warming Potential associated with cladding will be reduced by 90%.

Table 4. Environmental Burdens associated with Wall Assembly Components (per square foot).

Assembly Components	Environmental Impact Measure		
	Solid Waste kg	Air Pollution Index	Global Warming Potential kg
2X4 Lumber Studs	0.23	0.06	0.23
2X6 Lumber Studs	0.23	0.09	0.34
2X6 Lumber* Studs	0.21	0.04	0.19
2X4 Steel Studs	0.10	0.12	0.83
3.5" Rockwool	0.12	0.32	0.95
5.5" Rockwool	0.19	0.50	1.49
R13 Fiberglass	0.03	0.02	0.38
R19 Fiberglass	0.05	0.20	0.59
1.5" EPS	0.01	0.03	0.57
Recycled Paper Insulation	0.02	0.07	0.20
1 layer 5/8" gypsum	0.35	0.02	0.38
1 layer 1/2" gypsum reg	0.28	0.01	0.31
3/8" OSB	0.06	0.35	0.35
7/16" OSB	0.06	0.41	0.40
1/2" OSB	0.07	0.47	0.46
1/4" OSB*	0.04	0.23	0.23
1/2" OSB*	0.07	0.47	0.46
1/2" Plywood	0.01	0.03	0.11
1/4" Plywood*	0.01	0.01	0.06
1/2" Plywood*	0.01	0.03	0.11
3/8" Shiplap	0.01	0.03	0.08
Vinyl	0.07	0.17	0.82
4 mil Poly Vapor	0.00	0.01	0.06
6 mil Poly Vapor	0.00	0.01	0.08

* Indicates product produced with above-average levels of biofuels.

Note: the Global Warming Potential in Table 4 includes only the emissions from processing consistent with the CORRIM Research Guidelines for the Phase I Research Plan. Since the carbon stored in wood products is derived from a sustainably managed neutral carbon forest, carbon exported from the forest stored into wood products becomes an offset against other emissions (Perez-Garcia et al 2005b). The Phase II Guidelines were modified to directly link product carbon stores rather than to treat it as separate carbon pool from processing emissions.

5. Global Warming Potential (Carbon) Life Cycle Assessment of Wall and Floor Assemblies

While the comparative range of impacts on Global Warming Potential of 5 to 1 shown in figure 2 are based on processing energy impacts and do not include the impacts of carbon stored in products the tables that follow have been updated to include product carbon as an offset. Given the increasing importance of carbon mitigation, we select representative wall assemblies for Minneapolis and floor assemblies for Atlanta and include product carbon storage with the focus on best product selection and design configurations for carbon mitigation. We have limited the examples to the most basic components to better focus on those components producing the lowest carbon emissions.

Table 5 characterizes the basic components used in wall and floor assemblies and aggregates the impacts for selected structural assemblies leaving out insulation and interior cladding, but including exterior studs, sheathing and cladding in walls and joists and floor covering in floors. By focusing on the primary components in a structural assembly it becomes easier to identify dominant impacts important to environmental improvement strategy. Like the earlier estimates the ATHENA EIE model was used to measure carbon from forest regeneration through construction and the impacts normalized per sq. ft. of wall or floor. Carbon impacts from processing emissions are shown separately from carbon stored in products before summing for a GWP index. Total energy is listed separately for fossil and wood fuel sources. GWP is also normalized to the wood fiber usage as a measure of efficiency in using wood fiber to reduce emissions.

Table 5. Energy and Carbon Impacts for Wall and Floor Components and Assemblies

Wall Structures & Covering per SQF	Processing Emissions ($kg\ CO_2/ft^2$)	Total Energy (MJ/ft^2)	Fossil Fuel (MJ/ft^2)	Wood Fuel (MJ/ft^2)	Wood Fiber (kg/ft^2)	Product Carbon ($kg\ CO_2/ft^2$)	GWP ($kg\ CO_2/ft^2$)	GWP/ Wood Fiber
BioDried Stud	0.14	7.86	2.15	4.93	1.04	-1.25	-1.11	-1.06
KDStud	0.25	7.86	4.59	2.49	0.86	-1.25	-1.00	-1.16
SteelStud	0.93	12.32	11.40	0.00	0.00	0.00	0.93	Div/0
Concrete Block	6.08	81.42	74.11	0.00	0.00	0.00	6.08	Div/0
Plywood	0.16	7.10	3.80	2.58	0.81	-1.14	-0.98	-1.21
BioDryPly (more biofuel)	0.05	7.10	1.22	5.16	1.00	-1.14	-1.09	-1.09
OSB	0.51	16.50	9.34	5.85	1.12	-1.23	-0.72	-0.64
Vinyl	0.82	16.55	15.33	0.00	0.00	0.00	0.82	Div/0
BioDryStud /Ply/Vinyl	1.12	31.51	21.28	7.51	1.85	-2.39	-1.27	-0.69
BioDryStud /OSB/Vinyl	1.47	40.91	26.82	10.78	2.16	-2.48	-1.01	-0.47
KDWood/Ply/Vinyl	1.23	31.51	23.72	5.07	1.67	-2.39	-1.16	-0.69
KDWood/OSB/Vinyl	1.58	40.91	29.26	8.34	1.98	-2.48	-0.90	-0.45
Steel/Ply/Vinyl	1.91	35.97	30.53	2.58	0.81	-1.14	0.77	0.95
Steel/OSB/Vinyl	2.26	45.37	36.07	5.85	1.12	-1.23	1.03	0.92
BioDryStud/BioDryPly/BioDryPly	0.24	22.06	4.59	15.25	3.04	-3.53	-3.29	-1.08
BioDryStud/OSB/BioDryPly	0.70	31.46	12.71	15.94	3.16	-3.62	-2.92	-0.92
C.Block/Stucco	6.08	81.42	74.11	0.00	0.00	0.00	6.08	Div/0
1/2"Gypsum	0.31	7.66	7.08	0.00	0.00	0.00	0.31	Div/0
1/4" Ply	0.08	3.55	1.90	1.29	0.41	-0.57	-0.49	-1.21
R19 Cellulose	0.08	1.83	1.65	0.00	0.00*	0.00*	0.08*	Div/0
R19 Fiberglass	0.59	11.92	11.00	0.00	0.00	0.00	0.59	Div/0
Floor Structures & Covering per SQF								
Dimension Joist	0.34	10.52	6.32	3.14	1.09	-2.00	-1.66	-1.52
EWP I-Joist	0.33	7.74	5.78	1.24	0.42	-0.77	-0.43	-1.04
Steel Joist	3.68	47.93	44.69	0.00	0.00	0.00	3.68	Div/0
Concrete Slab	2.55	26.93	24.74	0.00	0.00	0.00	2.55	Div/0
Dimension/Ply	0.50	17.62	10.12	5.72	1.90	-3.48	-2.98	-1.57
Dimension/OSB	0.85	27.02	15.66	8.99	2.21	-4.05	-3.20	-1.45
EWP/Ply	0.49	14.84	9.58	3.82	1.23	-2.25	-1.76	-1.43
EWP/OSB	0.84	24.24	15.12	7.09	1.54	-2.82	-1.98	-1.28
Steel/Ply	3.84	55.03	48.49	2.58	0.81	-1.49	2.36	2.91
Steel/OSB	4.19	64.43	54.03	5.85	1.12	-2.05	2.14	1.91
Concrete Slab & barrier	2.63	28.65	26.37	0.00	0.00	0.00	2.63	Div/0

***** Does not take credit for extending wood life by using recycled wood

Table 6 provides direct comparisons between alternative wall and floor assemblies showing the amount of reduction in GWP that would be achieved by substituting one assembly for another. Abbreviations in component names are used to simplify titles for graphical comparisons.

Table 6. Global Warming Potential Reductions from Wall and Floor Component and Assembly Substitutions

	GWP Saved /Wood Fiber Used (kg CO_2/ft^2/kg dry wood)	**GWP Saved (kg CO_2/ft^2)**
CO_2 SAVED Wall or Floor Assemblies		
Stud Substitution		
Steel to BioDry Wood Stud	1.96	2.04
Steel to KD Wood Stud	2.24	1.93
Concrete to BioDry Wood Stud	6.91	7.19
Concrete to KD Wood Stud	8.23	7.08
Stud, Sheathing & Cladding Substitution		
Steel/Ply/Vinyl vs BioDry Stud/Ply/Vinyl	1.96	2.04
Steel/Ply/Vinyl vs KD Stud/Ply/Vinyl	2.24	1.93
Steel/OSB/Vinyl vs BioDry Stud/OSB/Vinyl	1.96	2.04
Steel/OSB/Vinyl vs KD Stud/OSB/Vinyl	2.24	1.93
Steel/OSB/Vinyl vs BioDry Stud/BioDry Ply/ BioDry Ply	2.25	4.32
Steel/OSB/Vinyl vs BioDry Stud/OSB/ BioDry Ply	1.94	3.95
ConcreteStucco vs BioDry Stud/ BioDry Ply/ BioDry Ply	3.08	9.37
ConcreteStucco vs KD Stud/OSB/Vinyl	3.52	6.98
KDStud/OSB/Vinyl vs BioDry Stud/ BioDry Ply/ BioDry Ply	2.27	2.39
CO_2 SAVED per Sq FOOT Floor Assemblies		
Joist Substituion		
Steel to Dimension	4.91	5.34
Steel to EWP	9.82	4.12
Concrete to Dimension	3.94	4.29
Concrete to EWP	7.31	3.07
Joist, covering & barrier substitution		
Steel/OSB vs EWP/OSB	9.82	4.12
Concrete vs EWP/OSB	3.00	4.61
EWP/Ply vs EWP/ OSB	0.70	0.22

6. Product and Process Environmental Improvement Analysis (Carbon Life Cycle Assessment)

While it is evident from the analysis of virtual house designs that wood framing is superior to concrete or steel alternatives just how to go about selecting specific products or process changes (such as biofuel drying) to reduce environmental burdens across many stages of processing benefits by understanding the burdens imposed by specific products and processes. As noted in figure 3, the wood floor-joist ***components*** that are used in the construction of floors (dimension wood joist {Dim-Joist} and Engineered Wood I-Joists {EWP I-Joist} both store carbon (negative emissions) as their emissions from processing are more than offset by the carbon stored in the products. In contrast, the non-wood Concrete Slab and Steel Joists result in substantial carbon emissions (2-4 kgCO_2/sq ft of floor). Adding a wood covering (plywood {Ply} or oriented strandboard {OSB}) to steel joists for a ***floor-assembly*** does not offset the emissions from the heavy gauge steel that is used in flooring. EWP I-joists with wood covering store less carbon than dimension joists because they use less fiber but all combinations of wood joist and wood covering store substantial amounts of carbon compared to non-wood joists and floor covering which result in significant emissions.

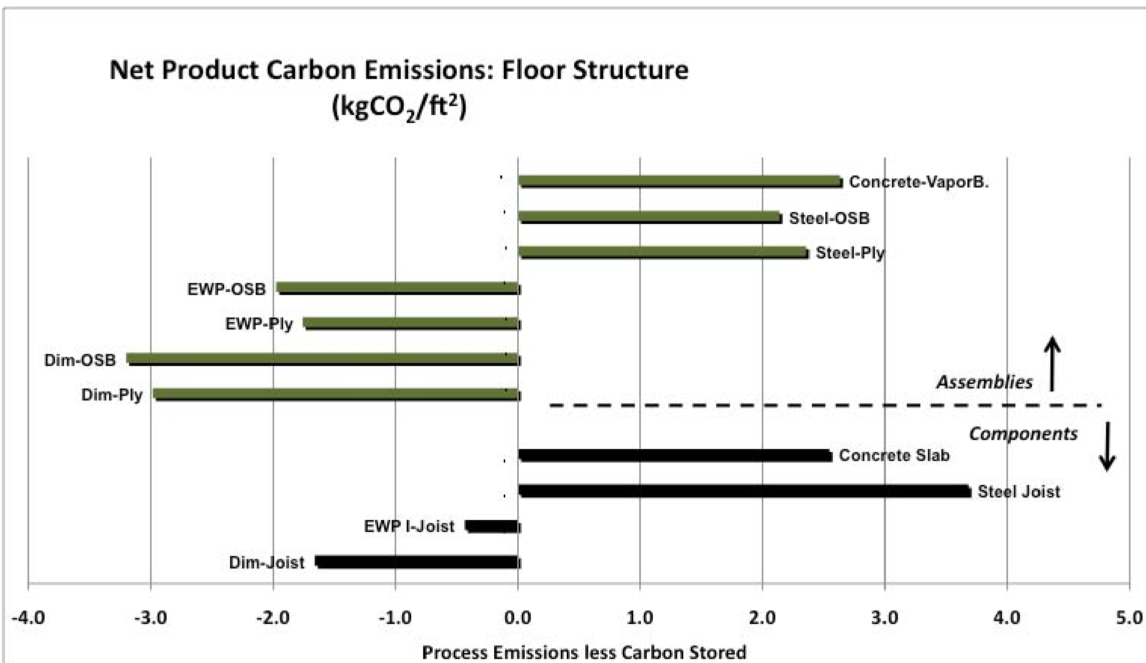

Figure 3. Process Emissions less Carbon Stored in Floor Structure Components and Assemblies

The reduction in GWP (carbon equivalent global warming potential) for competing ***floor-assembly*** designs are shown in figure 4. The EWP I-joist with an OSB cover is shown to displace GWP emissions relative to a Plywood cover alternative (top bars) simply because an OSB covering is more dense i.e. stores a little more carbon. It is substantially better than concrete reducing GWP emissions by 3 kg per sq. ft. of floor (middle bars). Another measure of interest is to measure the emission reduction relative to the fiber used as an efficiency of substitution measure. The EWP I-joist reduces CO_2 emissions by 4.6 kg per kg (dry weight) of wood used. The comparisons with steel (bottom bar) show the wood joist and cover reducing emissions by 9.8 kg per sq. ft., more than twice as effective as the substitution for a concrete floor largely because steel joists must be heavy gauge to minimize floor bounce resulting in substantial processing emissions, a relatively poor application for steel. But since the steel floor also uses wood in the floor cover as a partial carbon offset it is less fiber efficient reducing emissions to 4.2 kg per kg of wood used, slightly less than by displacing concrete flooring. If there is an adequate supply of wood, greater use of wood will improve the carbon footprint the most. If not, efficient use of fiber becomes important.

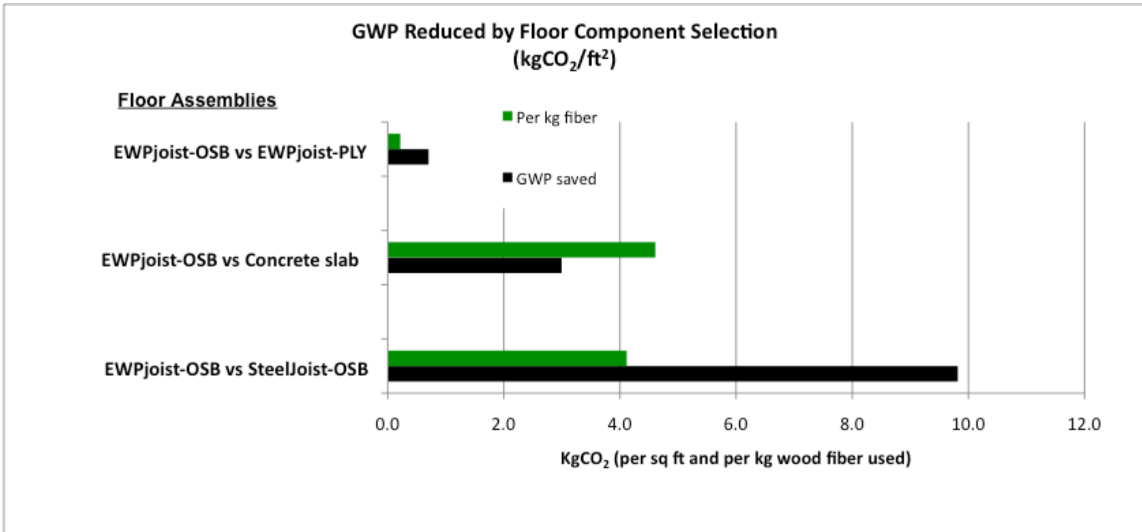

Figure 4. Reducing Global Warming Potential by Selecting Components in Floor Assemblies (per square foot and per kg of fiber)

While displacing steel in floors is more effective than displacing concrete these findings cannot be generalized to wall assemblies. As noted in figure 5, the wood-wall ***components*** (kiln dried stud {KDStud}, biofuel dried Stud{BioDryStud}), Plywood{Ply}), OSB, biofuel dried plywood {BioDryPly}) all store carbon more than offsetting their processing emissions, and some ***wall assemblies*** use sufficient amounts of wood to more than offset the emissions of some non-wood components such as the emissions from the use of vinyl cladding. As a component, concrete block substitutes not only for wood studs, but also the wood sheathing and with the addition of a stucco cladding for any wood or vinyl cladding used with wood framed walls. The worst assembly shown is Concrete Block and Stucco and the best configurations use wood products with biofuel used for drying as shown in the top three bars. The footprint for an un-dried stud (green stud) is the same as for a biofuel dried stud with respect to carbon stored and both would be graphed the same for emissions per square foot of construction although the latter uses more fiber as fuel reducing the emission reduction per unit of biomass used. The benefit of using more biofuel is within easy reach for both biofuel dried wood studs (BioDryStud) and plywood (BioDryPly) but are not shown for OSB, which in current use already has a higher share of biofuel for drying. For these examples the biofuel use level in both biodried studs and plywood was essentially double that of current average practice. The assembly made of biofuel dried studs, biofuel dried plywood sheathing and cladding stores the most net carbon with the use of OSB sheathing almost as good.

There are many opportunities for product development to improve products and construction assemblies beyond the basic designs shown and there may also be other environmental issues of importance requiring assessment. There will also be regional differences reflecting different energy sourcing and species dependent processing.

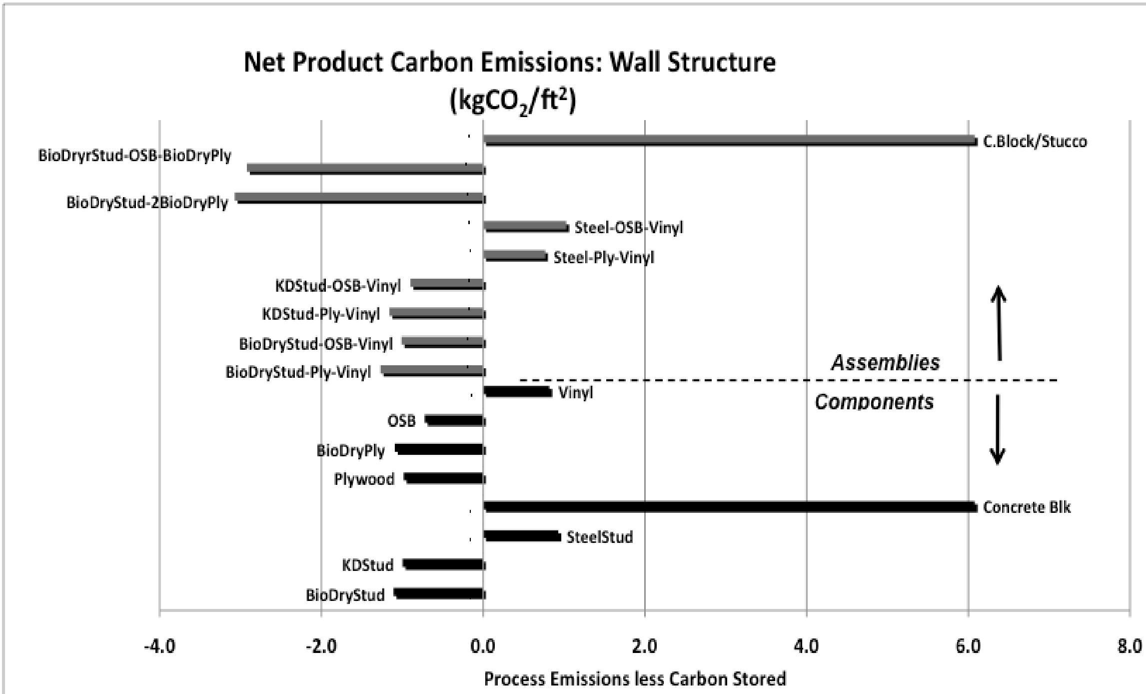

Figure 5. Process Emissions less Carbon Stored for Wall Components and Assemblies

The reduction in GWP by substituting competing designs including both product selection and biofuel drying process alternatives are shown in figure 6. The biofuel dried stud with biofuel dried plywood sheathing and cladding substitution for the more conventional kiln dried stud with OSB sheathing and vinyl siding reduces GWP by 2.2 $kgCO_2$ per sq. ft. of wall with a fiber efficiency of 2.1 kg CO_2 reduction per 1kg of fiber used (top bars). The benefit of this within wood substitution is almost the same as replacing a conventional steel wall assembly with a conventional wood assembly (bars), which involves no increased use of biofuel in drying. By doing both, increasing the use of biofuel and substituting for a steel framed wall assembly, GWP emissions are reduced by 4.1 $kgCO_2$ per sq. ft. of wall with a fiber substitution efficiency of 2.7 $kgCO_2$ per kg of wood fiber used.

Using the wood designs compared to a concrete and stucco wall result in GWP reductions of 7-9 $kgCO_2$ per sq. ft. of wall and 3.5 $kgCO_2$ per 1 kg use of fiber. While the wood is more effective at displacing the emissions from steel in floors and concrete in walls the displacement of emissions per unit of fiber is not as different. The use of more fiber is a substantial part of the opportunity for improvements but will not provide the high leverage possible by using wood fiber to displace more fossil intensive products such as steel joists vs EWP I-joists. However, different components do perform better in different applications and these differences are not generally identified or valued in current market exchanges.

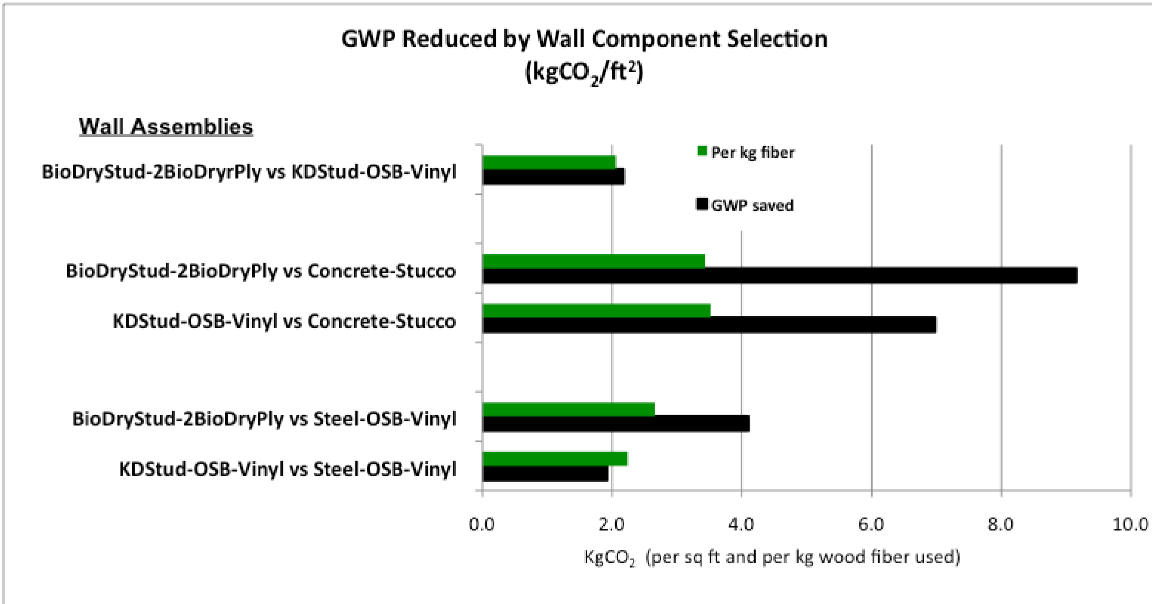

Figure 6. Reducing Global Warming Potential by Selecting Components in Wall Assemblies (per square ft of wall and per unit of fiber used)

7. Conclusions

This sampling of materials and designs is not exhaustive but suggests many design, product and process changes that can improve environmental performance. The most obvious include (1) using a renewable wood resource instead of a fossil intensive resource and especially where the substitution advantage is large, (2) using biofuels to reduce the fossil fuel use in manufacturing wood, (3) using resource efficient materials pre-cut to length or pre-assembled units as well as (4) using recycled materials that require less energy. The results also suggest the potential for many future improvements in the design of components that can displace the higher energy components and the design of new pre-assembled units that can gain several of these advantages at once. It should be noted that while using wood fiber for biofuel may effectively reduce fossil energy emissions, burning wood residuals that can be engineered into structural products maybe counterproductive as structural wood products can displace more emissions from fossil fuel intensive non-wood structural products (steel, concrete, aluminum, brick, plastics). Incentives that may divert such uses of wood fiber to energy only applications will be counterproductive to carbon mitigation objectives.

An important caveat in this analysis is the variation in impacts regionally. The figures shown here are reflective of assemblies that are part of a home built in Minneapolis or Atlanta. Regional differences in energy sources, production processes, and species availability can impact the associated energy and environmental burdens. While the impacts demonstrated here are expected to be important in any region, there may be regional differences as well as product, design, and construction method differences.

8. References

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